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Cement Loop Damage-based Fracture Mechanism during Repair of Casing Failure Well

NIU Jingtai[a,b], PENG Youwen[a], WU Congcong[b], WEI Bowen[b], a*

[a]*Nanchang institute of technology, Nanchang330099, China*
[b] *College of Water-conservancy and Hydropower, Hohai University, Nanjing 210098, China*

Abstract

Casing failure is a common problem in oilfield. This paper studies on cement loop damage during the repair of casing failure well based on the theories of composite materials mechanics, interface mechanics and damage mechanics, and a composite model was established. Through the model, the distributions of stress and displacement fields were obtained. Moreover, the influences of friction coefficient on interface were also studied. And the cement loop failure length is also determined. Finally, the case shows that the model is suitable for repairing casing failure better.

Keywords: casing failure, cement loop damage, mechanism study, failure length;

1. Introduction

Casing failure is a common problem in oilfield, which seriously affected the oil production. There are few research on cement loop damage during the repair of casing failure well [1]. Huang etc[2] analyze the factors that cement loop elastic modulus and thickness, casing wall thickness, the contact conditions of cement loop and casing influenced on casing and cement loop stress distributions.

After cementing, cement loop will form two cementation surfaces between stratum layer and casing. The cementation surface between cement loop and casing calls first cemented surface, and the other calls second cementation surface. In the repairing process, as external forces increase, making the bond strength decreased. In addition, when cementing is completed, because of initial defects that exist in the

* Corresponding author: NIU Jingtai. Tel.: +86-791-82086424.
E-mail address: niujingtai@163.com.

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consolidation surface and cement loop, the initial defects within the cement will cracking, then initial crack develop to form a macroscopic crack, so lead the cement capacity of consolidation and containment to decrease.

2. Mechanical model of composite materials

In the process of repairing casing failure wells, we look cementation surface between stratum and cement loop as matrix, casing as fiber, then the casing-cement loop-formation system can be abstracted as fiber composite materials, and the process of cement loop damage can be simulated as fiber-matrix debonding problem of fiber composite materials in the interface. [3-5]

Interface damage mechanic model of cement loop in the process of rolling plastic is showed as figure 1. Casing deformation take place at the H from the ground, and earth stress is σ_H . $0 \le z \le l$ is debonding area, and $l \le z \le s$ is bonding area. In order to facilitate the calculation, following assumptions are made: P is tensile load applied on the casing, that is: $P = \sigma_{zf}\pi(a^2 - b^2)$, z=0, where σ_{zf} is fiber stress in the z direction. Meanwhile, assume fiber and matrix as linear elastic material and ignore influence of volume force.

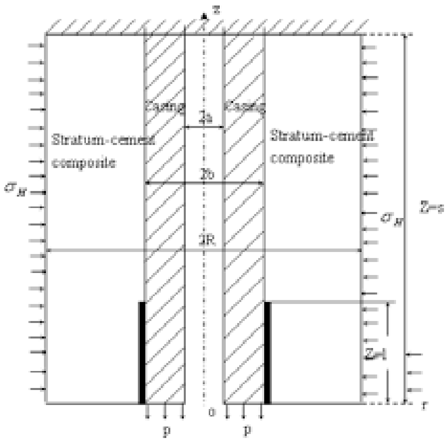

Fig1. Mechanical model

① bonding area

Stress and displacement meet continuous conditions, that is: $\lfloor \sigma_{ij}\eta_j \rfloor = 0 \quad [u_i]_\Gamma = 0$

② debonding area（$0 \le z \le l$）

Making reference to literature [4], stress-strain relationships of casing and matrix in the z direction can be expressed:

$$\varepsilon_{zf} = du_f/dz = [\sigma_f - \gamma_f(\sigma_{rf} + \sigma_{\theta f})]/E_f = (T_f/\pi(b^2 - a^2) - \gamma_f q_f^*)/E_f \tag{1}$$

$$\varepsilon_{zm} = du_m/dz = (T_m/\pi(b^2 - a^2) - \gamma_m q_m^*)/E_m \tag{2}$$

Where $E_f, E_m, \gamma_f, \gamma_m$ are Young's modulus and Poisson's ratio of casing and matrix respectively. T_m is load in matrix. There is shear stress acting on debonding zone, which meets Coulomb friction law. That is: $\tau_s = -\mu\sigma_n = -\mu\sigma_{rf} - \mu\sigma_{rm}$.

③ whole area.（$0 \le z \le s$）,we have $\sigma_{rm} = -\sigma_H \quad (r = R) \quad \sigma_{rF} = 0 \quad (r = a) \quad T_f + T_m = P$. The equilibrium equation in the z direction is: $dT_m/dz = -dT_f/dz = 2\pi b\tau_s \quad T_f = P \quad T_m = 0$

3. Stress-displacement field of casing-cement loop in the process of repairing casing failure well

From the mechanical model we know, the question is plane stain axisymmetrical problem. Stress and displacement distribution in casing can be obtained:

$$\sigma_{rf} = A_1/r^2 + B_1,\ \sigma_{\theta f} = -A_1/r^2 + B_1,\ u_{rf} = -A_1\left(1+\gamma_f\right)/r E_f + \left(\left(1-\gamma_f\right)B_1/E_f - \gamma_f/E_f\right)r \quad (3)$$

In matrix, the stress and displacement distributions are:

$$\sigma_{rm} = A_2/r^2 + B_2,\ \sigma_{\theta m} = -A_2/r^2 + B_2,\ u_{rm} = -\left(1+\gamma_m\right)A_2/rE_m + \left(\left(1-\gamma_m\right)B_2/E_m - \gamma_m\sigma_{zm}/E_m\right)r\ , \quad (4)$$

where A_1, A_2, B_1, B_2 are undetermined constants, which can determined by boundary conditions and interfacial continuous conditions.

When stress is applied, the displacements of casing and matrix can be determined by elastic constitutive equation, boundary conditions and continuous displacement conditions.

① bonding area（$l < z < s$） $u_f = (z-s)\left[P^* + \sigma_H^*\right]/E_f$

where P^* and σ_H^* represent the contributions of applied force and earth stress to the displacements of casing and matrix. .

② debonding area（$0 < z < l$）

Displacement intermittent quantity that generated in debonding zone is given by: $\upsilon(z) = \left|u_f(z) - u_m(z)\right|$

The calculated results of interfacial displacement difference and interfacial shear stress about friction coefficient are given by figures 2 and 3. We can come to the conclusion: with the increasing of friction coefficient, interfacial shear stress and the length of the rupture surface will increase. The largest shear will appear l is the largest. The maximum of displacement difference occur in the end, and increases with the friction coefficient increasing.

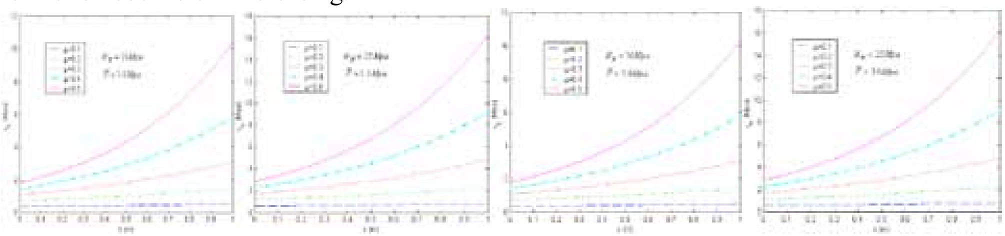

Fig.2 Influence of friction number to interface shear

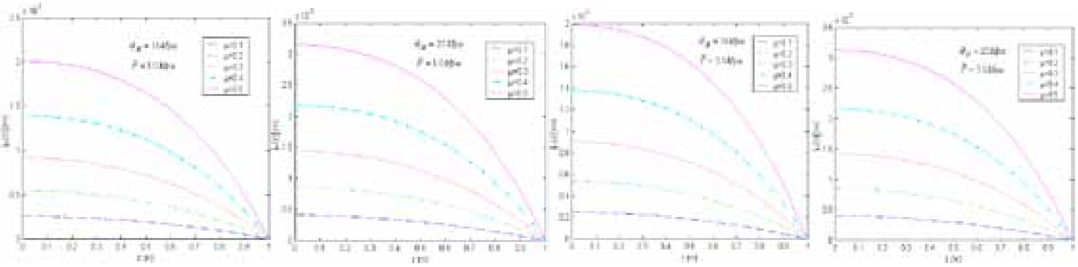

Fig.3：Influence of friction number to displacement

4. Determine failure length of cement loop

Shan [6] proposed the concept of debonding parameter ξ on fiber composite materials debonding problems, that is:

$$\xi = \frac{1}{2}\frac{\partial}{\partial S}\left[\int_{S_T} \vec{T}\delta\vec{u}ds - \frac{1}{2}\int_{S_F} \tau_s \delta v ds\right] \tag{5}$$

Using analysis and calculations prior to ,we can obtain:

$$4bA\alpha B^*\zeta/\left(b^2 - a^2\right) = \left[\alpha\left(A - 2c\gamma_f\right)\widetilde{P} - \left(2c - \gamma_m A\right)\widetilde{\sigma}_H - B^*\left(\alpha\gamma_f\widetilde{P} - 2\widetilde{\sigma}_H\right)\left(e^{\lambda l} - 1\right)/c\right]^2 \tag{6}$$

$$B^* = \left(\left(\alpha + c_f/c_m\right)A - 2c^2\right)$$

where equation(6) is debonding critical formula.

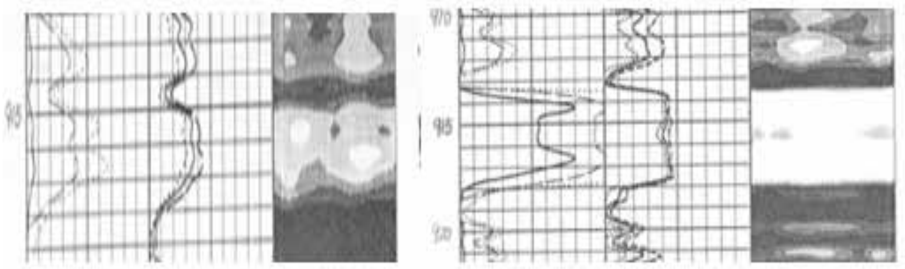

Fig4 Comparison test-chart for cement loop damage length before and after well is repaired

Figure4 gives comparison test-chart for cement loop damage length before and after well is repaired. From calculation, the results coincide with the measured data. Therefore, it also indicates the correctness of this paper theory.

5. conclusion

Using theories of composite materials mechanics, interface mechanics and damage mechanics, a composite model of stratum, cement loop and casing was established. Meanwhile, the distributions of stress and displacement fields were obtained. The results show that model is suitable when earth stress is small. In order to enhance the quality of repaired well, people should not only focus on improving technology, but also improve the properties of cement loop.

Acknowledgements

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